MOUNTING SYSTEM FOR OPTICAL FREQUENCY REFERENCE CAVITIES

PRIORITY

This application claims the benefit of U.S. Provisional Patent Application Nos. 60/711,955, filed Aug. 25, 2005, and 60/713,834, filed Sep. 2, 2005 and incorporates them herein by reference.

GOVERNMENT SUPPORT:

The present invention was made with government support as follows. NSF, Grant #s PHY00-96822, "the JLA Research Program in Atomic, Molecular, and Optical Physics", C. E. Wieman and W. C. Lineberger Office of Naval Research, N00014-02-1-0714, "Optical Atomic Clocks", Jun Ye NASA NAGS-10368, "Optical Local Oscillator with 1×10^{-15} Frequency Stability", J. Hall and J. Ye, ended Feb. 14, 2004

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to techniques for mounting optical frequency reference cavities in such a manner as to reduce the effects of mechanical vibration.

2. Problems in the Art

A common method of achieving optical frequency stability in a laser is to use a laser whose output frequency can be tuned with a control signal, and to stabilize (servo-lock) the laser frequency to a mode (or resonance) of a passive cavity, called an optical frequency reference cavity. Compared to the laser cavity, the reference cavity can be made far more stable, since it has no gain medium. The reference cavity might be a Fabry-Perot cavity such as a high finesse two-mirror cavity with a spacer between the mirrors formed of low thermal expansion coefficient material.

A number of techniques have been used to make the reference cavity even more stable. For example, the reference cavity mounting might include vibration absorbing damping elements, acoustic vibration isolation, temperature stabilized housing, etc.

Methods such as mechanical isolation (on a heroic scale), low pass filtering, or active anti-vibration approaches are sufficiently productive such that, by now several groups have developed visible optical sources with ~Hz linewidths. Further progress has been very challenging—all the margins have been used up. In addition, the most successful approach, active anti-vibration techniques, is expensive and complicated to implement.

One of the present inventors conceived of an idea to mount a reference cavity vertically at a single central plane, rather than horizontally as is conventional. See J. L. Hall, "Frequency Stabilized Lasers: a parochial review," *Proceedings of the SPIE,* 1837, 2-15 (1993). A second of the present inventors built and experimented with such a system. See: "Cryogenic system for a sapphire Fabry-Perot optical frequency standard," Cryogenics 1996, Volume 36, Number 1, pp 13-16. However, the stability challenges that were caused by the single plane mounting were thought to be too large to overcome at that time. In addition, the mounting mechanism used a clamping collar, which, as it turned out, squeezed and distorted the spacer cylinder and degraded performance. Until the present invention was made, no one in the field of optical frequency reference cavities felt that the vertical orientation would be workable.

Thus, there exists a need for an alternative technique for stabilizing optical reference cavities, by mounting the cavities vertically at their horizontal geometrical midpoint.

SUMMARY OF THE INVENTION

An object of the present invention is to provide an alternative technique for stabilizing optical reference cavities, by mounting the cavities vertically at their horizontal geometrical midpoint.

By using vertical symmetry relative to the horizontal midplane of an optical cavity, even large vibration induced distortions of the cavity's spacer result in near-zero net change in the distance between the cavity mirrors. This results in a cavity that is almost immune to vibrations, and hence can be used to obtain ultra-narrow laser linewidth.

The present invention provides an alternative technique for stabilizing optical reference cavities. The technique is based upon an improved mounting method for the cavity, wherein the cavity is mounted vertically at its horizontal geometrical midplane. Horizontal geometrical midplane is defined herein as a plane perpendicular to the axis along which light propagates, wherein the portion extending above the plane is geometrically equivalent to the portion extending below the midplane. This means that the mass above the plane is equal to the mass below the plane, and it is similarly oriented. This can mean the portion above the midplane is symmetrical (except for angular rotation) to the portion below, or that the two portions have been adjusted to have the same effect in their deformation of the distance between the support point and mirror to an applied acceleration (for example by adding small weights further from the midplane) even with a small dissymmetry.

In one implementation, the cavity is suspended at this plane, outside and around the spacer cylinder, equidistant from the mirror ends of the cavity. The suspension element is a collar of an extremely low thermal expansion coefficient material (LTE material), which surrounds the spacer cylinder and supports it uniformly. The spacer is also formed an LTE material, usually the same one. Once the collar has been properly located, it is cemented in place (for example with RTV Silicone bond) so that the spacer cylinder is uniformly supported and does not have to be squeezed at all.

Alternative embodiments form the collar and the spacer as an integral element. Various changes to the reference cavity have also been made to optimize its use with the mounting scheme of the present invention. The cavity is made shorter and lighter, in order to improve stability with the central mounting orientation.

The collar is a disk formed of an exceptionally low thermal expansion coefficient material, which is heat-treated and annealed by the manufacturer to have a minimum expansion point at around the temperature at which the reference cavity will be used. The collar must be ground rather than molded to retain its low thermal expansion properties.

In addition to the central axial bore into which the spacer cylinder is fitted, one preferred embodiment of the collar includes a number of cavities partially bored into its lower flat surface, around the axial bore. These cavities are support points, into which mounting base pins will be inserted. Hence the collar is supported at a minimum of three points. In a preferred embodiment, the support cavities include a layer of indium at their bases to smooth and broaden the contact area between the pins and the collar. To equalize the weight above and below the midplane, a corresponding set of dummy holes are bored into the top surface of the disk, with this family of